

Gauge Gravity and Space-Time

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Abstract

When we discuss problems on gravity, we can not avoid some fundamental physical problems, such as space-time, inertia, and inertial reference frame. The goal of this paper is to discuss the logic system of gravity theory and the problems of space-time, inertia, and inertial reference frame. The goal of this paper is to set up the theory on space-time in gauge theory of gravity. Based on this theory, it is possible for human kind to manipulate physical space-time on earth, and produce a machine which can physically prolong human's lifetime.

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1 Symmetries in Physics

It is found that basic physical laws of nature always show some kinds of symmetry. For example, the classical Newtonian mechanics has Galileo symmetry, Maxwell equations have Lorentz symmetry, and electrodynamics has $U(1)$ gauge symmetry. On the other hand, basic physical symmetries take an important role in the construction of a physical theory. Sometimes, it even acts as an important criteria for us to judge the rationality of a basic theory. In a meaning, the symmetry in physics implies the symmetry of the law of nature. Because of such symmetries of nature, a correct physical theory must preserve the same symmetry. In physics, the symmetries in basic physical laws play an important role in the construction of a basic physical theory. The study of symmetry is an important research field and method in the study of theoretical physics, especially in the study of modern physics.

There are mainly two kinds of symmetries in physics, one is the space-time symmetry, and another is the internal symmetry. Space-time symmetry is the symmetry that relates to the space-time coordinate transformations, and the internal symmetry is the symmetry of the transformation in the space of internal degrees of freedom of a physical field without changing space-time coordinates. In quantum field theory, the internal symmetries in most cases are gauge symmetries. The space-time symmetries are usually regarded as kinematical symmetries, while the internal symmetries in most cases are dynamical symmetries. Besides, there is a special symmetry, the gravitational gauge symmetry, which have the property of both the space-time symmetry and the internal symmetry. It is the gravitational gauge symmetry, which study the local space-time translation symmetry from the dynamical point of view[1, 2, 3, 4, 5, 6, 7].

Symmetry means the invariance of basic physical laws under mathematical transformations. From mathematical point of view, the set of these transformations forms a group. From the study of symmetries in physics, we can see the beautiful mathematical structure of a physical theory. Besides, we can study the conservation laws of nature. It is known that, according to Noether's theorem, there is a conservation law of the physical system which corresponds to each generator of the symmetry group. For example, the energy-momentum conservation law corresponds to the space-time translation symmetry, the angular momentum conservation law corresponds to the rotational symmetry of space, and the charge conservation law corresponds to the electromagnetic $U(1)$ gauge symmetry. Noether's theorem reveals the essential and positive connection between symmetry and conservation law[11].

2 The Idea of Gauge

In modern physics theory, the most important role of symmetry is not its relation to the conservation law, but that it provides a common rule for the construction of a theory on interactions. It is known that, soon after the foundation of quantum mechanics, the quantum mechanics that describing electromagnetic interactions is found to be a gauge invariant theory. After about 40 years, the unified electro-weak theory, which is a

$SU(2) \times U(1)$ gauge theory, is proposed. 10 years later, the quantum chromodynamics is founded. The quantum chromodynamics is a $SU(3)$ gauge theory which describing strong interactions between quark and gluon. An important inspiration that drawn from these great physical achievements is that these three kinds of fundamental interactions have a common nature, and are related to the same physical rule. It is important to understand this point, for it provides us a possible way to unify different kinds of fundamental interactions of nature.

Up to now, four kinds of fundamental interactions of nature are known by human beings. They are electromagnetic interactions, weak interactions, strong interactions and gravitational interactions. The first three are gauge interactions. An important idea that is drawn from the studying of the first three kinds of fundamental interactions is that the principle of local gauge invariance plays a fundamental role in a physical theory on interactions, and it determines the forms of interactions. So, a natural reaction of physicists is that gravity should also be a kind of gauge interactions, and the forms of gravitational interactions should also be determined by the principle of local gauge invariance. Studying along this direction, various kinds of gauge theory of gravity are proposed[8, 9, 10, 6]. Comparing to the traditional gauge theories, there are mainly two complexities for a gauge theory of gravity, one is that gravitational field is a spin 2 gauge field, another is the influence from the idea of the geometrization of gravity. Quantum gauge theory of gravity is proposed based on the gauge principle[1, 2, 3, 4, 5, 6, 7], and the traditional geometrization idea is not used in this theory. It is a perturbatively renormalizable quantum theory, and it can returns to general relativity for classical phenomenon of gravity. The quantum gauge theory of gravity is proposed based on the conviction that four kinds of fundamental interactions of nature should have common rule, and they can be unified based on this common rule[12, 13, 14, 15].

The core idea of gauge theory is gauge principle, which sets up the essential and inexorable relation between symmetry and interactions. In other words, it helps us to set up a systematic method to study interactions based on its symmetry. In gauge theory, when we determine a gauge symmetry, we can systematically set up the corresponding theory of interactions, and all details of the whole theory are almost uniquely determined by the gauge symmetry. Conversely, if there exists a kind of interactions, we can determine the corresponding gauge symmetry by gauge principle. A kind of interactions must have its source, and this source must be a conserved charge. According to Noether's theorem, this conserved charge must be the generator of a symmetry group. This symmetry group is the gauge group of the corresponding interactions. Based on this gauge group, we can set up the gauge theory of the interactions. But we know that, symmetry and interactions are two completely different concepts of physics. Symmetry is a word that describes static objects, while interactions are dynamic processes; symmetry is a word that describes the global feature of a physical system, while interactions mean changing in the local part of the system; symmetry is the language of geometry, while interaction is the language of physics. Though they are essentially different concepts, they are unified based on gauge principle. The heart and soul of quantum gauge theory of gravity is gauge principle.

3 Active Transformation and Passive Transformation

It is known that, in order to set up a gauge theory of fundamental interactions, the first thing we need to do is to determine the corresponding gauge transformation and gauge group. For gauge theory of gravity, the gauge transformation is space-time translation, for energy-momentum tensor is the generator of space-time translation. But there are two ways to perform space-time translation, one is active transformation, and another is passive transformation. In fact, for other kinds of transformations, such as Lorentz transformation and general coordinate transformation, these two ways of transformation still exist. For classical problems, active transformation and passive transformation are mathematically equivalent. Extending these mathematical equivalences to physics, we can obtain two important ideas of physics, they are the relativity principle and the equivalence principle. If what we discuss is Lorentz transformation, then the active transformation is the transformation that the physical object is boosted while our observer keeps still, which corresponds to the point of view of moving system; and the passive transformation is the transformation that our observer is boosted while the physical object keeps still, which corresponds to the point of view of moving observer. If we make them equivalent in physics, we will obtain the principle of special relativity, for this equivalence in physics means that fixed reference system and moving reference system are equivalent, which means that all inertial reference system are equivalent, for all of them are equivalent to the fixed reference system. If what we discuss is general coordinate transformation, the active transformation is the transformation that the physical object is boosted arbitrarily while our observer stands still, and our observer is an observer in an inertial reference system; and the passive transformation is the transformation that our observer is boosted arbitrarily while the physical object is fixed. In the later case, our observer is in a non-inertial reference system. If we make them equivalent in physics, we will find that all observers, no matter they are inertial or non-inertial, are equivalent. In fact, this is a part of the principle of general covariance. If our observer is in a local inertial reference system, this equivalence means that an inertial reference system and a local inertial reference system are equivalent, which is the idea of the equivalence principle.

However, active transformation and passive transformation have different pictures in physics. Active transformation is the transformation that is made directly on the physical system. When we make local transformation, we will change structure or states of the system. So it is a physical operation on the system. In another words, it is a physical transformation. Passive transformation is a coordinate transformation, it is a mathematical transformation. It does not cause any changes on the structure or states of the system. In other words, the symmetry of active transformation is an internal symmetry, while the symmetry of passive transformation is a space-time symmetry. From theoretical point of view, active transformation and passive transformation are only two different ways that we mathematically describing a transformation, but the physics that we study are the same. In this meaning, they must be equivalent. However, though they are equivalent, they may let to different physical theories. Let's return back to the theories of gravity. If we use the point of view of passive transformation in our study, the local space-time translation is just the general coordinate transformation. It is known that the best way to study the general coordinate transformation of a physical field is to use the tensor theory.

In order to keep the invariance of a physical system in general coordinate transformations, we need to introduce the concept of curved space-time. And after the introduction of the concept of curved space-time, the theory is complete, and there is no space for us to introduce the concept of gravitational field into the theory. A basic physical idea generated in this study is that gravity is only an effect of the curved space-time[16, 17, 18, 19]. So, in general relativity, the concept of curved space-time is fundamental, it is an inevitable result of the theory. The concept of gravitational field is a subsidiary concept of curved space-time. But if we use active transformation in our study, local space-time translation is just the gravitational gauge transformation. In this case, space-time keeps unchanged, while physical field undergoes some transformations. We use the language of gauge transformation to describe these changes. In order to keep the invariance of our physical system under gauge transformations, what we need to do is to introduce the corresponding gauge field into our theory. This gauge field is just the gravitational gauge field. In this case, we have no chance to introduce the concept of curved space-time into our theory. So, in gauge theory of gravity, the concept of gravitational gauge field is fundamental, and the concept of curved space-time can not be introduced into the theory. So, when we study the same physical problem, different treatments in mathematics will cause great discrepancies on thoughts of physics.

4 Absolute Space-Time and Physical Space-Time

In classical limit, quantum gauge theory of gravity can return to general relativity. So, in a meaning, we can say that, for classical problems of gravity, two theories are equivalent mathematically. But two theories are not equivalent physically, for they have different ideas on space-time. In general relativity, space-time is curved, and gravity is only an effect of curved space-time. In general relativity, there does not exist the concept of absolute space-time. In gauge theory of gravity, gravitational field is a physical field which exists in space-time. So, gravity and space-time are two concepts which are independent each other. The independence of gravity and space-time means that there should exist a space-time which is not affected by gravity. This space-time is the absolute space-time, which is always flat. In gauge theory of gravity, the absolute space-time is a theoretical tool which is introduced transcendentally. It is independent of matter, in other words, it will undergo no changes when there are matters exist in it. It is a transcendental basis of gauge theory of gravity. But the space-time used by us in the real world is the physical space-time, because the space-time of our real world is affected by matter in it. In other words, the so called time and space defined in physics are affected by classical gravitational field. The time and space used by an observer in an experiments are physical time and space, not the time and space of absolute space-time. The physical time and space are variable, and their changes are mainly caused by classical gravitational field. Let's study how time is defined in physics. It is known that the time itself is not directly perceptible, we feel the existence of time by various effects of motion. In physics, the time is defined by effects of motion. We have many methods to define the time in physics. For example, the old-fashioned pendulum clock defines the time through the period of

vibration of a pendulum, the traditional mechanical clock defines the time through the period of vibration of a spring oscillator, quartz clock defines the time through the period of vibration of a quartz crystal, and atomic clock defines the time through the period of oscillation of atomic spectrum. In all these methods, what are used to define the time are effects of motion, not time itself. Once classical gravitational field is introduced into space-time, these effects of motion will be changed, and all of them will be changed at the same manner. This result hold both in general relativity and gauge theory of gravity. It is known that classical gravitational field will put the influence to all motions of matter and interactions at the same manner and the same magnitude, no matter they are atom, molecular, quark, or gravitational field itself. These influences are the so-called time dilation effect and length contraction effect. So, when classical gravitational field is introduced into space-time, the vibration period of a pendulum, of a spring oscillator, of a quartz crystal, and of atomic spectrum will be changed the same manner and the same magnitude. Because the changes of them all have exactly the same step, there do not exist any relative changes when we compare these changes each other. Therefor, local observer can not feel any changes of them. Local observer makes a conclusion that, though the classical gravitational field of surroundings is changed, the frequency of his clock undergoes no changes. But a remote observer will find that the frequency of the clock used by the local observer is changed. This is just what the gravitational red shift experiment tells us. For the remote observer, the classical gravitational field of his surroundings are very weak, so the time given by his clock is approximately equal to the absolute time. Though the space-time of our real world is not absolute space-time, the introduction of absolute space-time into quantum gauge theory of gravity is necessary and inevitable. In quantum gauge theory of gravity, in order to study quantum effects of gravitational field and the influence of gravity to clock and ruler, we need a space-time frame which is not affected by gravitational field. On the other hand, in order to study the law of the changes of time and space of physical space-time, the introduction of absolute space-time is necessary. Now, in order to grasp the concepts of absolute space-time and physical space-time, let's do an ideal experiment. Suppose that there is an gravity machine, which will be called Magic Gravity Box(MGB). We suppose that MGB is a hi-tech machine that can change the magnitude of gravitational potential inside MGB without any influence to the gravitational potential outside MGB. We suppose that the gravitational potential inside MGB is uniform, and the spacial derivative of gravitational potential is small, so people in it will not feel very strong gravity. Now, let's start our ideal experiment with our MGB. In the first step, let's return back to the time of about 500,000 years ago. At that time, a group of apes live near Beijing. They live in a huge hole in the Zhoukoudian mountain. One day, they return back to the hole after hunting. They put their stone knife and stone axe into their hole home, then they roast their preys on fire and feast themselves in front of the hole. After that, they are singing and dancing to celebrate their success in hunting. Finally, they return their hole and sleep except one ape. Only one ape was asked to go into the MGB to experience magic life in it. After he go into the MGB, we adjust parameters of the MGB so that the parameter $(1 - gC_0^0)$ inside it is about 500,000. In the next day, Other apes awake after sunrise. They find that one of their partner is missing. They agitate and search him everywhere. Finally, they find him in a box with one meter long. They find that the ape in the MGB is as small as a grain of

dust, his heart stop beating, and everything in the MGB keeps motionless. However, the ape in the MGB does not feel that he undergoes any changes. His heart keeps beating as before, and his height is also the same as before. But he is flabbergasted when he observes outside world through the window of the MGB. His partners become as large as a huge mountain, and the fine hair of his partners is huger than a big tree. He find that the box is very huge, and the distance from the most east end to the most west end is about 50 kilometers. When his heart beats every time, there are six sunrise and sunset outside. He live in the MGB for about one year. He feel quite loneliness, and he ask to let him out to find his partners. Then, the parameter $(1 - gC_0^0)$ is adjusted to 1 to let him out. After he goes out, the first thing he want to do is to find his partners in the hole, for he miss them very much. But he find that everything was changed greatly. The hole he ever lives in disappears, the small river that flows past the hole also disappears, and the mountain is also changed greatly. None of his partners is found. He falls into a depression, and walks hit or miss. Suddenly, he found that there is a museum, and he walks into it. He find the osseous remains of his partners become fossilized and is displayed there. The stone knife and the stone axe, which are used by him one year before, are also displayed there as rare treasures. He is full of agony, for he has lost all partners, including his friends and all his relatives. He dashed around like a bat out of hell. He run into a huge city which is built of steel and cement. The city is full of people and an Olympic game is held there. Some people find that an ape is running in the street and report it to the police. Finally, the ape is caught by policemen. Archeologists find that the ape looks like Zhoukoudian ape. So, scientists are ask to do DNA identification. DNA identification shows that he is just the Zhoukoudian ape. Scientists can not understand how can he pass through 500,000 years time and still alive now.

The above description looks like a ugly science fiction. But here, MGB is used to help us understand the great difference between the space-time inside MGB and that out of MGB, which correspond to the physical space-time and absolute space-time respectively. It should be stated that MGB is not a pure fictitious machine. Of course, both classical Newton's theory of gravity and Einstein's general relativity do not allow us to built such a machine on earth. But, some quantum effects of gravity may help us to built such a machine on earth, and quantum gauge theory of gravity can provide us a theoretical guide on this study. Here, we will not go deep into the theory and technology of MGB, which will be discussed in other papers. Now, let's return back to the concept of space and time. Outside MGB, the gravitational field is very weak, so the space-time used by the observer outside MGB is approximately absolute space-time. However, inside MGB, the gravitational potential is very strong, the clock and ruler used by the observer inside MGB strongly affected by the gravitational potential inside MGB, so the space-time inside MGB is a physical space-time. From the point of view of an observer in absolute space-time, the time interval between ticks of a clock and length of a ruler will be changed when gravitational potential is changed, but the structure of space-time itself undergoes no change. From the point of view of an observer in physical space-time, the time interval between ticks of a clock and length of a ruler undergo no change when gravitational potential is changed. But this invariance is only a relative invariance, for their absolute magnitudes are changed.

In general relativity, the physical gravitational field is not transcendently introduced, for

gravitational field appears as an effect of curved space-time. In general relativity, physical space-time is a transcendental concept. It is not necessary to introduced the concept of absolute space-time, and there is no existential space for the concept of absolute space-time. It is known that the concept of absolute space-time is not consistent with the logic system of general relativity, for the existence of the concept of the absolute space-time need an implicit transcendental hypothesis that the existence of gravity is independent of space-time, or gravity is not an internal structure of space-time. From the point of view of quantum gauge theory of gravity, physical space-time is a composite existence of absolute space-time and gravitational field. Therefore, if physical space-time is treated as a transcendental concept in a theory, neither absolute space-time nor physical gravitational field can be treated as transcendental concepts. The logic system of quantum gauge theory of gravity is quite different. In gauge theory of gravity, absolute space-time is a transcendently introduced. It is a logic starting point of the theory. Gravitational field is a physical field existing in the absolute space-time. It is independent of space-time. In other words, it is an independent physical field, not an internal part of space-time. In gauge theory of gravity, the influence of gravity to clock and ruler is explained by the point of view of interactions between matter and gravitational field. What that gravity is treated as an independent physical field in gauge theory of gravity requires that the concept of space-time and the concept of gravity should be independent each other. In other words, when we define space-time, or define clock and ruler of space-time, there should exist no physical field in space-time. In this case, the space-time is absolute space-time. So, general relativity and quantum gauge theory of gravity have great differences on the concept of space-time.

5 Physical Picture of Gravity and Geometric Picture of Gravity

Some people may ask such question like that space-time is flat or curved, or the universe we live in is flat or curved? If it is flat, it can not be curved, or if it is curved, it can not be flat. For example, you hold a ball on your hand, no people will say that the surface of the ball is flat. But if you hold a plate glass on your hand, no people will say that its surface is curved. So, according to our ordinary experience of life, it is indeed true that if something is flat, it can not be curved, or if it is curved, it can not be flat. But for our universe, its space-time structure is flat or curved? In order to answer this question, we need to set up the representation theory of gravity. In fact, similar questions exist in physics. Let's return back to the Galileo's era of about 500 years ago. At that time, we faced a similar question. Suppose that there is a table placed in a small cabin of a ship which is sailing slowly in the sea. Our question is that the table is at rest or is moving? If you sit in the boat, you will say that the table is at rest; but if you stand in the seabeach, you will say that the table is moving. Two answers are completely contradict. Which answer is correct? Galileo study this problem, and two revolutionary ideas are generated from the study, the relativity principle and the inertial principle. According to Galileo principle of relativity, all motions are relative. If you want to describe a motion, you need first to

determine an observer, or select a reference system. In order to answer the question that the table is at rest or is moving, you need first to give a clear definition to the concepts of rest and motion, or say that you need first select a reference system. A reference system can be regarded as a representation of kinematics, and we will obtain different results in different representations of kinematics. Next, let's return back to the time of about 100 years ago. At that time, Heisenburg found matrix mechanics. In matrix mechanics, operators of physical quantities change with time, while quantum states are fixed. Soon after, Schrodinger found wave mechanics. In wave mechanics, quantum states change with time, while operators are fixed. It is found that both theories can explain almost all quantum phenomena observed in experiments at that time, but hypothesis of two theories are completely contradict. Physicists want to know which theory is correct? But final answer is exceeding all people's expectation, that is, both theories are correct. The key point to understand it is the introduction of the concept of the representation of quantum theory. Now, we know clearly that the wave mechanics founded by Schrodinger is the Schrodinger picture of quantum theory, and the matrix mechanics founded by Heisenburg is the Heisenburg picture of quantum theory. Two pictures are finally equivalent. Two pictures study the same microscopic phenomenon by using different mathematical tools from different point of view, but obtain the same final results. But what is the exact reason that cause the divergence of two pictures? Essentially speaking, the reason originates from the question of active transformation or passive transformation, in other words, the question of the transformation of system or the transformation of observer. It can be called the relativity principle of transformation. We can make such a correspondence: a wave function of quantum states can be regarded as a basis of quantum states, which corresponds to the coordinate system in classical mechanics, and an operator can be regarded as a quantum object, which corresponds to the matter system in classical mechanics. The developing of a quantum system can be describing in two ways. One way is to adopt the idea of active transformation, that is the wave functions are fixed while the operators are changing with time, which is just the Heisenburg picture of quantum theory. Another way is to adopt the idea of passive transformation, that is the operators are fixed while the wave functions are changing with time, which is just the Schrodinger picture of quantum theory.

Now, let's return back to the topic of gravity theory. In fact, we face similar questions. It is known that, in traditional gauge theory, the conserved charge given by global gauge symmetry is just the source of gauge interactions. We suppose that this rule holds for gravity theory. We know that the source of gravitational field is energy-momentum, and energy-momentum is the conserved charge of space-time translation symmetry. Therefore, the symmetry of gravity theory is the space-time translation symmetry. There are two mathematical ways to describe space-time translation, which will generate two different representation of gravity theory. One way is to use the manner of passive transformation. In this way, physics system is fixed while space-time coordinates undergo translations. After localization, the localized space-time translations are just the general coordinate transformations. In order to keep invariance of gravity theory under general coordinate transformations, arbitrary space-time metric and the concept of curved space-time are introduced into the theory. It is found that, when the concept of curved space-time is introduced into the theory, an independent gravitational field can not be introduced into

the theory, for the effect of curved space-time is just gravity. Studying in this way, what we obtained is just general relativity. In this theory, the concept of curved space-time is transcendental and fundamental, and gravity is only a subsidiary effect. General relativity has clear geometrical features, so we call it geometric picture of gravity. Another way is to use the manner of active transformation. In this method, space-time coordinates are kept unchanged while physical system undergoes some transformations. This is the manner that we usually used to describe symmetry transformations in gauge field theory. In gauge field theory, what we study is gauge transformations, i.e., the gravitational gauge transformations. In order to keep local gauge symmetry of the theory, we need to introduce gravitational gauge field, which transmits gravitational interactions. Because we perform no operations on the structure of space-time, the structure of space-time are kept unchanged under gravitational gauge transformations. Therefore, in quantum gauge theory of gravity, space-time is always flat, or say that we have no reason to introduce the concept of curved space-time into the theory. So, in quantum gauge theory of gravity, the concept of absolute space-time is transcendental, whose existence is independent of gravity, and gravity is a physical field which exists in absolute space-time. In other words, space-time and gravity are two independent concepts in quantum gauge theory of gravity. The theory constructed in this manner is physics picture of gravity. In geometrical picture of gravity, space-time is physical space-time, so it is a curved space-time; while in physics picture of gravity, space-time is absolute space-time, so it is flat.

6 Clock and Ruler

Next, let's study the problem from a more fundamental point of view. An obvious question is that, which mechanism causes space-time curved? In other words, how to understand the mechanism of space-time curving? Or say that, from physical point of view, why space-time in general relativity is curved, while it is flat in gauge theory of gravity? Suppose that we are mathematicians. In this case, we just study mathematical problems from mathematical point of view. We can make any hypothesis on the structure of space-time without considering the structure of space-time of our real world. Suppose that there is a space-time. Before we make any further hypothesis on the structure of space-time, it's structure is unknown, or say that, it can be either flat or curved. Once the metric of the space-time is determined, the structure of the space-time is determined at the same time. So, we conclude that the structure of space-time is determined by its metric. But, what is the physical nature of metric? From physical point of view, the key role of metric is to define clock and ruler. Different definitions of clock and ruler will give out different structures of space-time. The difference between different definitions of clock and ruler in physics is that the exterior physical environments are different. In physics, we have very strict restrictions on the definitions of clock and ruler, and the purpose of these strict restrictions is try to reduce the influence from exterior environments. For example, the temperature of the instrument should be precisely set to a given value, and the strength of electric field and magnetic field should be small enough. It is known that both the time interval between ticks of a clock and the length of a ruler are affected by tempera-

ture, strength of electric field and magnetic field. They are also affected by gravitational field in space-time, but in the definition of clock and ruler, we make no restrictions on the strength of gravitational field, which causes different definitions of clock and ruler in physics and different structures of space-time. It is known that the time interval between ticks of a clock and the length of a ruler are affected by gravitational potential, which are the famous time dilation and length contraction effects. In order to avoid interference from gravitational potential, a natural requirement is that, in the standard definition of clock and ruler, the gravitational potential should be zero. When we adopt this definition, we will find that our universe is flat, and our space-time is absolute space-time. On the other hand, though gravity can change the time interval between ticks of a clock and the length of a ruler, for a local observer, all these changes are not observable, for in a local reference system, all physical processes undergo the same changes which keeps all relative magnitudes unchanged. For a local observer, all measurements are to determine the value of relative magnitude, not of absolute magnitude. Though gravity can change the time interval between ticks of a clock and the length of a ruler, a local observer can not feel these changes. In other words, the local observer can not find that his clock and ruler undergo any changes. For the sake of convenience, he would like to use his clock and ruler to define time and space without any modifications from gravity. The manner that to use the clock and ruler in a local inertial reference system to define time and space is used by general relativity. If we adopt this manner to define time and space, we will find that our universe is curved and our space-time is physical space-time. The key mechanism that make our universe curved is that we use a clock and a ruler which have different absolute magnitude in different point of space-time. Therefore, that our universe is flat or curved is not determined by existence, but by the clock and ruler selected by physicist. In this meaning, the role of the equivalence principle can be regarded as to define clock and ruler for a local system, or say that, it make the clock and ruler in a local inertial reference system equivalent to the clock and ruler in an inertial reference system. The clock and ruler defined in this manner contains the effects of gravity. Therefore, the effects of gravity are naturally put into space-time metric, and gravity becomes a part of inner structure of space-time. So, the definition of clock and ruler in general relativity is empirical, which is a natural selection from the point of view of a local observer, while the definition of clock and ruler in absolute space-time is transcendental, which is a natural selection from the point of view of a theorist.

General relativity and quantum gauge theory of gravity have quite different theoretical structures and mathematical formulations. In fact, all these differences originate from their different transcendental hypothesis. Some of these hypotheses are not clearly mentioned in the standard formulation. We can only find them in the implications of traditional formulations. These hypotheses contain the hypothesis of the nature of gravity, the hypothesis on the nature of space-time, the hypothesis on the nature of inertial, and the definitions of clock and ruler. The theoretical foundation of general relativity is the equivalence principle. The nature of the equivalence principle is to set up the equality of a local inertial reference system and an inertial reference system, and the nature of this equality is to set up another equality of the clock and ruler in a local inertial reference system and the clock and ruler in an inertial reference system. The nature of the second equality is to put the effects of gravity into space-time metric, and therefore to

make gravity to be a part of space-time metric. In this case, our natural results are that the curved space-time is a basic and transcendental concept, and gravity is a subsidiary concept, which is only an effect of curved space-time. Quantum gauge theory of gravity inherits basic ideas and treatments of quantum field theory. In quantum gauge theory of gravity, gravity is treated as a kind of physical interactions which exists in space-time. What implicates in this manner of treatment is the hypotheses that gravity and space-time are two transcendental concepts, and they are independent of each other. Since gravity and space-time are independent of each other, or say that gravity is an exterior object of space-time. In the definition of clock and ruler, our natural requirement is that the local gravitational potential should be zero. Or say that, the clock and ruler in a local inertial reference system can not be used to define time and space. In this case, our space-time must be absolute space-time. It can not be curved, for there does not exist any mechanism that can make space-time curved. In fact, when we try to construct a physical theory, we can always supposed that our space-time is transcendently flat, for we can always take out all possible mechanisms that can make space-time curved from the inner structure of space-time. These mechanisms can be treated independently as an independent physical process.

7 Inertial Reference System

Another important difference between general relativity and quantum gauge theory of gravity is the definition of an inertial reference system. It is known that an inertial reference system is a special kind of coordinate system in which the equations of motion can hold in their usual form. In classical mechanics, an inertial reference system is at rest in absolute space-time, or in a state of uniform motion with respect to absolute space-time. In general relativity, this definition is essentially changed. In general relativity, a local inertial reference frame is considered to be a kind of inertial reference frames. As stated above, the physics nature of the equivalence principle is to define clock and ruler, or say that to define space-time metric. Under this definition, gravity disappears in this local system, space-time becomes local flat, and the equations of motion can hold in their usual form in this local space-time. From the point of view of a local observer, this local reference frame is almost the same as the inertial reference frame. But for an observer in absolute space-time, even if in local space-time, the local inertial reference frame is not an inertial reference frame, for in the local inertial reference frame, there exist both gravity and inertial force, the observer in it falls freely, and the clock and ruler used by him are changed continuously. So, for an observer of absolute space-time, the equations of motion can not hold in their usual form in this local system. Of course, if we redefine clock and ruler at each point of space-time, or say that redefine metric of space-time, we can make gravity and inertial force exactly cancel each other at each point in the local space-time, and the equations of motion returns to their usual forms in the local space, which is just the treatment of general relativity.

What determines the inertial reference system? What is the origin of inertial force? In fact, quantum gauge theory of gravity can not answer such kinds of questions. In quantum

gauge theory of gravity, absolute space-time is introduced transcendentally, or say that, it is the logical starting point of the whole theory. According to definition, an inertial reference system is at rest in absolute space-time, or in a state of uniform motion with respect to absolute space-time. This definition means that an inertial reference system is also introduced into the theory transcendentally. They are also logical starting point of physics. We can consider this question from another point of view. Suppose that there is a free mass point, which has no physical interactions with exterior environments. According to energy-momentum conservation law, the energy-momentum of the mass point must be a constant, or say that, its velocity is always a constant. So, it must be at rest or in a state of uniform motion. Before we make this conclusion, we must select a reference system first. But, if we select a non-inertial reference system, we can not obtain such conclusion. We will find that the mass point moves arbitrary, and its energy-momentum changes arbitrary. For the observer in the non-inertial reference system, the magnitude of this change can not be predicted, and the cause of this change is also unknown. In this case, it is difficult to construct a scientific kinematical theory. It is known that, in order to construct a scientific theory, a key requirement is that there should be no effect if there is no cause. In other words, for a free mass point, if it has no interactions with exterior environments, its energy-momentum should be a constant. According to this requirements, the only reference system that we can select is an inertial reference system. After an inertial reference system is defined, how to understand the non-inertial reference system? In fact, if we do not allow to change our clock and ruler freely, we will find that there does not exist any non-inertial reference system in nature. In other words, the physical nature of a non-inertial reference system is that the observer in the non-inertial reference system uses variable clock and ruler. For an observer in absolute space-time, the observer in a non-inertial reference system is in a state of variable motion. According to special relativity, the clock and ruler used by the observer in a non-inertial reference system are changed when velocity is changed. When an observer uses these variable clock and ruler in the measurement, he will find that his reference system is a non-inertial reference system. Suppose that there is a mass point which is at rest in a non-inertial reference system. An observer in absolute space-time will find that the mass point moves in variable velocity, and its energy-momentum varies continuously. According to classical mechanics, this mass point must feel a force from exterior environments. According to Newton's third law of motion, there must be a reacting force, which is the inertial force observed by the non-inertial observer. From the point of view of reference frame transformation, the inertial force is a physical effect of a residual term of reference frame transformation. Therefore, inertial force is not a kind of real physical interactions. Essentially speaking, the physical origin of inertial force is the using of variable clock and variable ruler in the observation. Or say that, inertial force is a residual physical effect of variable clock and variable ruler. It is not a kind of physical interactions.

What determines an inertial reference system? In fact, such kind of questions is beyond the research field of physics, for an inertial reference frame is the transcendental foundation of both classical physics and modern physics. Up to now, there does not exist a physical theory of a non-inertial reference frame. Discussions on inertial itself can only be performed philosophically. If we discuss it in physics, we will discuss an inertial frame by using results of an inertial frame, which is a logic ring. In fact, an inertial frame

is the most natural frame in physics. When we perform physical study, we need firstly remove all possible interference from exterior environments, and isolate the object of our study from exterior environments. The object should have no physical interactions and no energy-momentum exchange with exterior environments. This isolated system must be at rest in absolute space-time, or in a state of uniform motion with respect to absolute space-time. The frame fixed in this system is the inertial frame. In fact, any frame which fixed in a free mass point is an inertial frame.

8 Logic System

In general relativity, because of the equivalence principle, a local inertial frame is considered to be a kind of inertial frame, which make the concepts of space-time, inertial and gravity are entangled with each other. In quantum gauge theory of gravity, the concept of gravity is independent from the concepts of space-time and inertial. Gravity is treated as a kind of fundamental interactions. This is the important perceptive difference between two theories. The goal and motivation of quantum gauge theory of gravity are to study quantum effects of gravitational interactions. In order to study quantum gravity, it is important to separate gravity from structures of space-time, for we can not put quantum graviton into the structure of space-time. There are two reasons. One reason is that we can not select a local inertial frame, in which the quantum graviton disappears. Or say that, we can not select a local inertial frame, in which all effects of quantum gravity are shielded. Another reason is that the probabilistic quantum wave function of quantum gravitational field can not be put into the metric of space-time.

We notice that the origin of the great difference between two theories is from the equivalence principle. For the equivalence principle, different theorists have different interpretations on its physics role. The idea of the equivalence principle comes from the consideration of the physics in a free fall elevator. In a free fall elevator, the inertial force and gravity exactly cancel each other, which is the physical reason that finally give birth to the equivalence principle. Because of the equivalence principle, the local inertial reference frame is regarded as a kind of inertial reference frame, which can be explained in another way that all effects of gravity are completely shielded in the local inertial reference frame. In fact, such kind of explanation is not correct, and is not logically necessary. Strictly speaking, not all effects of classical gravity can be completely shielded in the local inertial reference frame. Only effects of classical gravito-electric field can be shielded in the local inertial reference frame, effects of classical gravito-magnetic field can not be shielded. A classical example is the spin-spin interactions[20, 21, 22, 23, 24]. A satellite which is in an orbit around the earth can be regarded as a free falling frame. Owing to the spin-dependent force, the gyroscope is neither relatively static, nor uniform rectilinear moving, but oscillating with increasing amplitude. The existence of this oscillation means that the gyroscope feels gravitational force in the free falling frame, which violates the weak equivalence principle. However, what the effects of classical gravity can be observed in a local inertial frame does not violate the rationality of general relativity. As we have stated before, the physical nature of the equivalence principle is to define clock and ruler,

or the space-time metric. In fact, for the logic system of general relativity, the principle of general covariance is relatively more important and more fundamental. In the construction of general relativity, the principle of general covariance plays a key role, which brings gravity into mathematical formulation of general relativity. From the point of view of quantum gauge theory of gravity, the principle of general covariance is the geometrical version of gauge principle. The logic system of general relativity is as below

1. the clock and ruler, or the metric of space-time, are selected by defining a local inertial reference frame,
2. gravity is introduced into the mathematical formulation of general relativity through the principle of general covariance, and base on it, the physics in curved space-time is set up,
3. the space-time metric, or the gravitational field in space-time, is calculated by solving Einstein's field equation.

The logic system of quantum gauge theory of gravity is as below

1. transcendently introduce an absolute space-time, and define the corresponding clock and ruler, which are not affected by gravitational field in space-time,
2. the gravitational field in space-time is determined by solving the field equation of gravitational gauge field,
3. the interactions between gravity and ordinary matter field are determined by gauge principle.

References

- [1] Ning WU, "Gauge Theory of Gravity", hep-th/0109145.
- [2] Ning WU, Commun. Theor. Phys. (Beijing, China) **38** (2002): 151-156.
- [3] Ning WU, "Quantum Gauge Theory of Gravity", hep-th/0112062.
- [4] Ning WU, "Quantum Gauge Theory of Gravity", talk given at Meeting of the Division of Particles and Fields of American Physical Society at the College of William & Mary(DPF2002), May 24-28, 2002, Williamsburg, Virgia, USA; hep-th/0207254; Transparency can be obtained from: <http://dpf2002.velopers.net/talks-pdf/33talk.pdf>
- [5] Ning WU, Commun. Theor. Phys. (Beijing, China) **42** (2004): 543-552.
- [6] Ning WU, "Renormalizable Quantum Gauge General Relativity" gr-qc/0309041.

- [7] Ning Wu, *Quantum Gauge Theory of Gravity*, In *Focus on Quantum Gravity Research*, chapter 4, ed. David C. Moore, pp.121-169, (Nova Science Publishers, Inc., New York, 2006)
- [8] F.W.Hehl, P. Von Der Heyde, G.D.Kerlick, J.M.Nester Rev.Mod.Phys. **48** (1976) 393-416
- [9] D.Ivanenko and G.Sardanashvily, Phys.Rep. **94** (1983) 1.
- [10] J.-P.Hsu, Int. J. Mod. Phys. **A21** (2006) 5119.
- [11] D. Lurie, *Particles and Fields*, Interscience Publishers, John Wiley and Sons, New York, 1968.
- [12] Ning WU, Commun. Theor. Phys. (Beijing, China) **38** (2002): 322-326.
- [13] Ning WU, Commun. Theor. Phys. (Beijing, China) **38** (2002): 455-460.
- [14] Ning WU, Commun. Theor. Phys. (Beijing, China) **39** (2003): 561-568.
- [15] Ning WU, *Unified Theory of Fundamental Interactions*, In *Quantum Gravity Research Trends*, chapter 3, ed. Albert Reimer, pp. 83-122, (Nova Science Publishers, Inc., New York, 2006)
- [16] Albert Einstein, Annalen der Phys., **49** (1916) 769 .
- [17] Albert Einstein, Zeits. Math. und Phys. **62** (1913) 225.
- [18] S. Weinberg, *Gravitation and Cosmology: Principles and Applications of the General Theory of Relativity*, John Wiley, New York, 1972.
- [19] N. Straumann, *General Relativity and Relativistic Astrophysics*, Springer-Verlag, Berlin Heidelberg New York Tokyo, 1984.
- [20] M.Mathisson, Acta Phys. Pol., **6**, (1937):163.
- [21] J.Lubanski, Acta Phys. Pol., **6**, (1937):356.
- [22] A.Papapetrou, Proc.Roy.Soc., **A209**, (1951):248; E.Corinaldesi and A.Papapetrou, Proc.Roy.Soc., **209**, (1951):259.
- [23] A.H.Taub, J. Math. Phys., **5**, (1964):112.
- [24] Ning WU, Commun. Theor. Phys. (Beijing, China) **49** (2008): 1533-1540.